Renewable and Sustainable Energy Reviews 18 (2013) 1–5

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review on solar energy utilisation in Australia

Alireza Bahadori [a,*], Chikezie Nwaoha [b]

[a] Southern Cross University, School of Environment, Science and Engineering, Lismore, NSW 2480, Australia
[b] Independent Consultant, Nigeria

ARTICLE INFO

Article history:
Received 8 June 2012
Received in revised form
5 October 2012
Accepted 8 October 2012
Available online 1 November 2012

Keywords:
Solar thermal energy
Solar PV energy
Australia
Clean energy
Renewable energy

ABSTRACT

Climate change due to greenhouse gases emission from fossil fuels has prompted several governments to channel resources in the commercial utilisation of renewable energy sources. Solar energy is one of the renewable energy sources that is highly untapped and underutilized. Australia has the highest average solar radiation per square metre of any continent in the world. This paper will focus on the need to improve solar energy utilisation in Australia, challenges facing it and the future benefits. This study shows successfully storing and transferring solar energy will ensure that this energy source will make a significant contribution to Australia's electricity grid supply in the future and Australia will be well positioned to assist in meeting its growing clean energy demand.

Contents

1. Introduction

To overcome the negative impacts on the environment and other problems associated with fossil fuels have forced many countries to enquire into and change to environmental friendly alternatives that are renewable to sustain the increasing energy demand. Solar energy is one of the best renewable energy sources with least negative impacts on the environment [17].

There are several different methods of harnessing the energy from solar radiation from the sun. These are active solar heating, passive solar heating and solar engines for electricity generation. Active solar energy use is normally used for domestic heating or water heating such as solar hot water systems that are common across Australia due to the low cost of running and government subsidies offered [19]. Whilst this method of capturing solar energy can reduce electrical consumption, these types of systems

* Corresponding author. Tel.: +61 2 6626 9412.
E-mail address: alireza.bahadori@scu.edu.au (A. Bahadori).

1364-0321/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2012.10.003

are generally not used in large scales and have inherent efficiency and cost problems [19].

Passive solar heating is more about improving the passive efficiency of housing and other buildings. This includes passive heating devices that use the energy in solar radiation to heat a building and circulate the cold air out from the room. This includes Conservatory, Trombe wall and direct gain type applications [13].

The most relevant source of solar renewable energy with regard to electricity generation is the solar heat engine. Generally reflective mirrors are used to focus the radiation onto a source of water or other fluid then by evaporating the liquid the steam is used to in a turbine to power a generator. There are many types of plant outlay with different arrangements of focusing the radiation [21].

Commonwealth Scientific and Industrial Research Organisation (CSIRO) predicts that by 2050 around 30% of Australia's energy supply will come from solar power [8].

In Australia, the commercialisation of renewable energy has not developed in any way close to matching the R&D expertise that has been shown by Australian scientists in solar power. The first serious wave of renewable energy uptake did not start until as late as 1997 when Australian Government declared Australia's commitment to developing renewable energy as part of its energy plan to reduce carbon emissions [10]. As a result, a market for renewable energy was created by specifying a Mandatory Renewable Energy Target (MRET) in 2001 for which electricity retailers needed to purchase 'green' or renewable energy certificates which could be surrendered according to the obligatory amount prescribed to them [10].

There has been very strong political opposition in Australia in any public policy attempt to stop the use of coal so as to reduce carbon emissions [10].

1.1. Advantages of solar energy

Solar energy is obviously environmentally advantageous relative to any other energy source, and the linchpin of any serious sustainable development programme [17]. It does not deplete natural resources, does not cause CO_2 or other gaseous emission into air or generates liquid or solid waste products. Concerning sustainable development, the main direct or indirectly derived advantages of solar energy are the following [17]:

- No emissions of greenhouse (mainly CO_2, NOx) or toxic gasses (SO_2, particulates).
- Reclamation of degraded land.
- Reduction of transmission lines from electricity grids.
- Improvement of quality of water resources.
- Increase of regional/national energy independence.
- Diversification and security of energy supply.
- Acceleration of rural electrification in developing countries.

As a result of concerns about climate change, increase in energy consumption rate, international agreements to reduce the GHGs emission and thinking about the availability of solar energy governments worldwide are beginning to establish national goals for the provision of electricity from renewable energy and hence try to set-up the various solar energy policies in various countries [17].

1.1.1. Primary energy consumption

Australia's primary energy consumption of solar energy accounted for 2.4% of all renewable energy use and around 0.1% of primary energy consumption in 2007–08 [3].

Production and consumption of solar energy are the same, because solar energy can only be stored for several hours at present. Over the period from 1999–2000 to 2007–08, Australia's solar energy use increased at an average rate of 7.2% per year. However, the growth rate was not constant; there was considerable variation from year to year.

The bulk of growth over this period was in the form of solar thermal systems used for domestic water heating. PV is also used to produce a small amount of electricity. In total, Australia's solar energy consumption in 2007–08 was 6.9 PJ (1.9 TWh), of which 6.5 PJ (1.8 TWh) were used for water heating [3].

1.2. Primary limitations of widespread use of solar energy

While high investment costs currently represent a barrier to more widespread use of solar energy, there is considerable scope for the cost of solar technologies to decline significantly over time. The competitiveness of solar energy will also depend on government policies.

Government policies and falling investment costs and risks are projected to be the main factors underpinning future growth in world solar energy use.

The outlook for electricity generation from solar energy depends critically on the commercialisation of large-scale solar energy technologies that will reduce investment costs and risks.

Relatively high capital costs and risks remain the primary limitation to more widespread use of solar energy. Government climate change policies, and research, development and demonstration (RD&D) by both the public and private sectors will be critical in the future commercialisation of large scale solar energy systems for electricity generation.

2. Australia's solar energy overview

Below are some facts with regard to Australia's solar energy:

- The annual solar radiation falling on Australia is approximately 58 million petajoules (PJ), approximately 10,000 times Australia's annual energy consumption [4].
- Solar energy resources are greater in the north-west and centre of Australia, in areas that do not have access to the national electricity grid. Accessing solar energy resources in these areas is likely to require investment in transmission infrastructure.
- There are also significant solar energy resources in areas with access to the electricity grid. The solar energy resource (annual solar radiation) in areas of flat topography within 25 km of existing transmission lines (excluding National Parks), is nearly 500 times greater than the annual energy consumption of Australia [4].
  - While the areas of highest solar radiation in Australia are typically located inland, there are some grid connected areas that have relatively high solar radiation. Wyld Group and MMA [18] identified a number of locations that are suitable for solar thermal power plants, based on high solar radiation levels, proximity to local loads, and high electricity costs from alternative sources. Within the National Electricity Market (NEM) grid catchment area, they identified the Port Augusta region in South Australia, north-west Victoria, and central and north-west New South Wales as regions of high potential for solar thermal power. They also nominated Kalbarri, near Geraldton, Western Australia, on the south-west Interconnected System, the Darwin-Katherine Interconnected System, and Alice Springs-Tennant Creek as locations of high potential for solar thermal power.

- Consumption of solar thermal energy, by state: Western Australia has the highest solar energy consumption in Australia, contributing 40% of Australia's total solar thermal use in 2007–08. New South Wales and Queensland contributed another 26% and 15% respectively. The rate of growth of solar energy use over the past decade has been similar in all states and territories, ranging from an average annual growth of 7% in the Northern Territory and Victoria, to an average annual growth of 11% in New South Wales. A range of government policy settings from both Australian and State governments have resulted in a significant increase in the uptake of small-scale solar hot water systems in Australia. The combination of drivers, including the solar hot water rebate, state building codes, the inclusion of solar hot water under the Renewable Energy Target and the mandated phase-out of electric hot water by 2012, have all contributed to the increased uptake of solar hot water systems from 7% of total hot water system installations in 2007 to 13% in 2008 [5,3].

With the global population reaching 7 billion people, and projected to increase to 8.6 billion in 2035—Australia can play a key role in ensuring these people to get access to a reliable source of energy [16].

From Fig. 3, northern and central Australia could prove to be a good candidate for solar energy gathering though due to the size of the array needed and the power transmission infrastructure the idea is prohibitive on a cost basis and is not commercially viable until more improvements in the technology have been made.

In 2002 830 GWh of solar energy was gathered in Australia although the majority of this, 61%, was used purely as domestic solar water heating [19]. Therefore as of 2002 only 36.5 MW of power generated from solar energy was fed into the national grid [19]. Further ABARE data has shown that this figure has risen to an electricity generating capacity of around 71 MW in the year 2007. Solar energy has great potential for electricity generation due to large areas of inland desert with high average temperatures year round and low percentage of cloud cover and rain. The infrastructure however necessary for such projects would require a large amount of capital and the cost per unit of electricity generated is generally higher than other fossil fuel based on renewable energy sources. The secondary main problem is the transmission infrastructure which would be a significant added cost as a result of the remoteness of the deserts in Australia and the distances between prospective sites and the population centres where the current power grids exist.

While the areas of highest solar radiation in Australia are typically located inland, there are some grid connected areas that have relatively high solar radiation. Australia's modest production and use of solar energy is focussed on off-grid and residential installations. While solar thermal water heating has been the predominant form of solar energy used to date, production of electricity from PV and concentrating solar thermal technologies is increasing.

Australia's total PV capacity has increased significantly over the last decade, and in particular over the last two years. This has been driven primarily by the Solar Homes and Communities Plan for on-grid applications and the Remote Renewable Power Generation Programme for off-grid applications. Over the last two years, there has been a dramatic increase in the take-up of small scale PV, with more than 40 MW installed in 2009.

This is due to a combination of factors: support provided through the Solar Homes and Communities programme, greater public awareness of solar PV, a drop in the price of PV systems, attributable both to greater international competition among an increased number of suppliers and a decrease in worldwide demand as a result of the global financial crisis, a strong Australian dollar, and highly effective marketing by PV retailers.

Most Australian states and territories have in place, or are planning to implement, feed-in tariffs. While there is some correlation of their introduction with increased consumer uptake, it is too early to suggest that these tariffs have been significant contributors to it. The combination of government policies associated public and private investment in RD&D measures and broader market conditions are likely to be the main influences.

3. Solar photovoltaics (PV)

Solar power, involving the conversion of solar energy to electricity, has undergone a dramatic expansion worldwide, which primarily reflects the reduced cost and greater conversion efficiency of photovoltaic cells [9].

There are several ways to harness the energy of the sun [1,11]. The most widely recognised method for generating electricity using solar power is by using Solar Photovoltaic (PV) systems. PV panels on the roofs of homes and businesses capture the sun's energy to generate electricity cleanly and quietly [12]. Light energy is converted directly into electricity by transferring sunlight photon energy into electrical energy. This conversion takes place within cells of specially fabricated semiconductor crystals [6]. Today solar PV power is installed on around 25,000 homes across Australia.

Solar PV also has a long history of supplying reliable 'off the grid' power to outback and regional communities, with isolated telecommunications and repeater stations, transport signalling, and working properties supported by a large number of solar PV installations [6]. Despite the country having reputation for a hot dry and sunny climate that would make it ideal for utilisation, less than 2% of energy is sourced from solar power.

Photovoltaic systems are well suited to off-grid electricity generation applications, and where costs of electricity generation from other sources are high (such as in remote communities) [4].

The issue for the Australian photovoltaics industry today is that there is enormous market potential but the industry is not yet self sustaining [12]. The main impediment to growth is the lack of a consistent national policy that recognises the contribution solar PV can make the Australia's climate change response [6]. Another principal constraint affecting widespread adoption of solar photovoltaic (PV) remains the lack of storage, hence electricity can only be supplied during daylight hours [7].

4. Solar thermal

Solar thermal also referred to as Concentrated solar power (CSP), involves the concentration of solar radiation which is then converted to steam to drive a conventional turbine or engine for electricity generation purposes [7]. This differs from solar PV in that the heat may be stored, commonly through using molten salts or oil as the liquid medium in the solar receiver, thereby enabling electricity to be generated outside of sunlight hours [7]. Furthermore, solar thermal offers the ability to match increased supply during periods of intense summer radiation with peak demand associated with space cooling requirements.

Solar thermal is commonly used for hot water systems. Solar thermal electricity, also known as concentrating solar power, is typically designed for large scale power generation.

Solar thermal technologies can also operate in hybrid systems with fossil fuel power plants, and, with appropriate storage, have the potential to provide base load electricity generation. Solar thermal technologies can also potentially provide electricity to

remote townships and mining centres where the cost of alternative electricity sources is high [4].

5. Current research & development (R&D)

CSIRO is a world leader in solar research. Their challenge today is to harness solar power to reduce Australia's dependence on fossil fuels. As renewable energy becomes more and more important in lowering greenhouse gas emissions, CSIRO is making solar power more efficient and effective [8].

CSIRO is committed in making photovoltaic solar cells – a commercialised, readily available solar technology – cheaper, longer lasting and more environmentally sustainable.

Photovoltaics (PVs) involve the conversion of light into electricity at the atomic level. Materials are selected or designed to absorb photons of light and release electrons. When these electrons are captured, electricity is created [8].

Most of today's commercially available solar cells are made from high purity semi-conductor or solar grade silicon, which make the cells expensive.

CSIRO is investigating new organic and inorganic materials (for example plastic) that will create the next generation of solar cells—they will be lighter, more flexible, attractive and most importantly, cheaper [8].

CSIRO's current photovoltaic projects include [8]:

- Victorian Organic Solar Cell Consortium
- Dye-sensitised solar cells
- Organic solar cells
- Solar intermittency study
- Characterisation.

6. Australian government policies

Australia as a country has formulated solar energy policies in reducing dependence on fossil fuel and increasing domestic energy production by solar energy and renewable energy at large.

Government policies have been implemented at several stages of the solar energy production chain in Australia. Rebates provided for solar water heating systems and residential PV installations reduce the cost of these technologies for consumers and encourage their uptake. The expanded RET scheme includes the *Solar Credits* initiative, which provides a multiplied credit for electricity generated by small solar PV systems. *Solar Credits* provides an up-front capital subsidy towards the installation of small solar PV systems.

The Australian Government has also allocated funding to establish the Australian Solar Institute (ASI), which will be based in Newcastle. It will have strong collaborative links with CSIRO and Universities undertaking R&D in solar technologies. The institute will aim to drive development of solar thermal and PV technologies in Australia, including the areas of efficiency and cost effectiveness [14]. Other government policies, including feed-in tariffs, which are proposed or already in place in most Australian states and territories, may also encourage the uptake of solar energy.

6.1. Renewable energy fund (REF)

The aim of renewable energy fund is to accelerate commercialisation and deployment of renewable energy technologies in Australia. The $500 million REF funds is available on a 1:2 basis, with the aim of leveraging over $1.5 billion in renewable energy investment to assist Australia to achieve its 20% renewable electricity target by 2020 [20]. $100 million over 4 years has been allocated to the establishment of an Australian Solar Institute, which is to cover PV and solar thermal electric research [20].

6.2. Solar flagship programme

The Australian Government has also announced $1.5 billion of new funding for its Solar Flagships programme. This programme aims to install up to four new solar power plants, with a combined power output of up to 1000 MW, made up of both PV and solar thermal power plants, with the locations and technologies to be determined by a competitive tender process. The programme aims to demonstrate new solar technologies at a commercial scale, thereby accelerating uptake of solar energy in general and providing the opportunity for Australia to develop leadership in solar energy technology [15].

6.3. Solar Institute

The Australian Government is committed in developing a suite of cost-effective low-emission energy technologies and has set a renewable energy target of 20% by 2020.

The Australian Government is investing heavily in renewable energy technologies and last year established the $500 million Renewable Energy Fund and the $150 million Energy Innovation Fund, $100 million of which is allocated to the establishment of the Australian Solar Institute [14]. The Institute's national headquarters will be located in Newcastle, New South Wales.

Inadequate funding for Australian research institutions and the lure of well funded overseas organisations has contributed to Australia losing solar research expertise throughout the past decade.

The Australian Solar Institute will provide much needed support for the Australian solar community, helping to retain Australian solar expertise and develop the next generation of Australian solar researchers. The Institute will foster greater collaboration between researchers in universities, research institutions, and industry and help forge strong links with peak overseas research organisations [14]. The Institute will make Australia a more attractive and productive location for solar researchers.

The institute will aim to drive development of solar thermal and PV technologies in Australia, including the areas of efficiency and cost effectiveness [14].

Establishing the Australian Solar Institute will [14]:

- advance and accelerate innovation in solar thermal and solar photovoltaic technologies in Australia;
- drive research capable of improving the efficiency and cost-effectiveness of solar technologies;
- increase the competitiveness of solar technologies;
- retain local and attract international expertise in solar energy research; and
- establish Australia as a key player in the development of solar energy technologies in the Asia-Pacific region.

7. Conclusion

Fig. 1 shows projected electricity generation from solar energy in Australia and Fig. 2 shows briefly the projected primary consumption of solar energy in Australia.

Australia has the highest average solar radiation per square metre of any continent in the world, and yet solar energy accounts for only 2.3% and 0.015% (solar PV and solar thermal

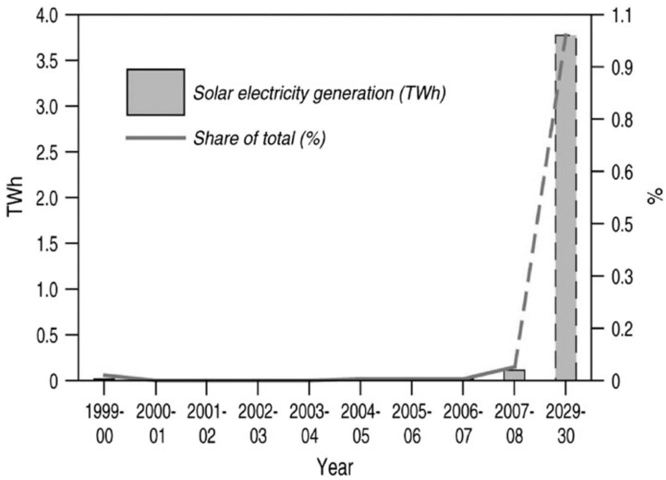


Fig. 1. Projected electricity generation from solar energy in Australia [2,3].

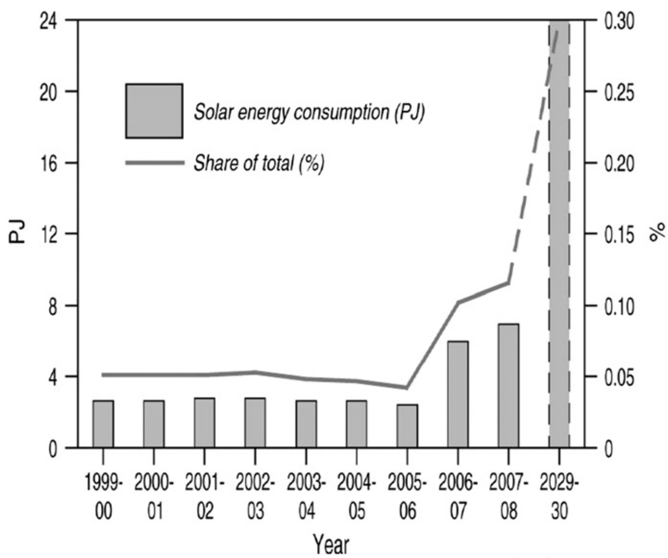


Fig. 2. Projected primary consumption of solar energy in Australia [2,3].

respectively) of power generation. In addition, the annual solar radiation falling on Australia is approximately 58 million petajoules (PJ), approximately 10,000 times Australia's annual energy consumption. With the abundant solar energy resource, the Clean Energy Council in its *Clean Energy Australia Report* 2011 *stated that* the number of Australian households with solar panels increased more than 35 times over the last three years. Despite this improvement, solar energy use in Australia is projected to increase by 5.9% per year to 24 PJ in 2029–30. Successfully storing and transferring solar energy will ensure that this energy source will make a significant contribution to Australia's electricity grid supply in the future. With the government policies in place and well implemented, Australia will be well positioned to assist in meeting its growing clean energy demand.

Solar energy commercial-scale generation projects have been demonstrated to be possible but the cost of the technology is still relatively high, making solar less attractive and higher risk for investors. Small-scale solar PV arrays are currently best suited to remote and off-grid applications, with other applications largely dependent on research or government funding to make them viable.

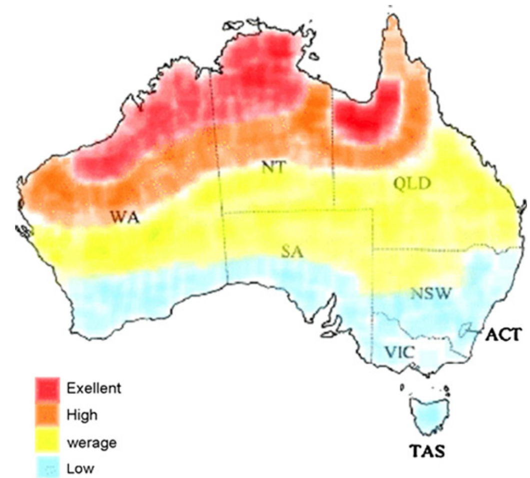


Fig. 3. Potential sites suitable for solar electricity generation [1].

References

[1] Australian Bureau of Agriculture and Resources Economics, Energy in Australia, Canberra Department of Resources Energy and Tourism;2009.

[2] ABARE, Australian Bureau of Agricultural and Resource Economics, Australian energy projections to 2029–30, ABARE research Report 10.02, prepared for the Department of Resources, Energy and Tourism:Canberra;2010.

[3] ABARE, Australian Energy Statistics:Canberra;August 2009.

[4] Australian Government Department of Agriculture, fisheries and forestry, Australian energy resource assessment—Chapter 10, Canberra ACT:Australia;2011.

[5] BIS Shrapnel, Hot water systems installed in new dwellings in Australia, North Sydney;2008 〈http://www.bis.com.au/reports/hot_water_systems_nd_in_aust.html〉.

[6] Clean Energy Council. Clean energy fact sheets all about solar photovoltaic. Melbourne: Clean Energy Council; 2008.

[7] Clifton J, Boruff BJ. Assessing the potential for concentrated solar power development in rural Australia. Energy Policy 2010;38:5272–80.

[8] CSIRO, Commonwealth Scientific and Industrial Research Organisation, Solar power: energy from the sun;2010. Available from: 〈http://www.csiro.au/Outcomes/Energy/Renewables-and-Smart-Systems/solar-power.aspx〉 (updated 31.05.12).

[9] Currie MJ, Mapel JK, Heidel TD, Goffri S, Baldo MA. High-efficiency organic solar concentrators for photovoltaics. Science 2008;321(5886):226–8.

[10] Effendi P, Courvisanos J. Political aspects of innovation: Examining renewable energy in Australia. Renewable Energy 2012;38:245–52.

[11] Geoscience Australia, Renewable energy power stations:2009 〈http://www.ga.gov.au/renewable/operating/operating_renewable.xls〉.

[12] Kuwahata R, Monroy CR. Market stimulation of renewable-based power generation in Australia. Renewable and Sustainable Energy Reviews 2011;15:534–43.

[13] Mathews JA. Carbon negative biofuels. Journal of Energy Policy 2007;36: 940–5.

[14] RET, Department of Resources, Energy and Tourism, Australian solar institute fact sheet:2009a 〈http://www.ret.gov.au/energy/Documents/ASI%20Fact%20sheet%2014Jan%20cleared%20by%20MO.pdf〉.

[15] RET, Solar flagships programme fact sheet:2009b 〈http://www.ret.gov.au/energy/Documents/Solar%20Flagships%20factsheet%20-%20Oct%202009.pdf〉.

[16] RET, Department of Resources, Energy and Tourism, Australian launch of the IEA world energy outlook:2011. Available from: 〈http://minister.ret.gov.au/MediaCentre/Speeches/Pages/IEAWorldEnergyOutlook2011.aspx〉.

[17] Solangi KH, et al. A review on global solar energy policy. Renewable and Sustainable Energy Reviews 2011;15:2149–63.

[18] Wyld Group and MMA, High temperature solar thermal technology roadmap. Prepared for the NSW and Victorian governments by Wyld group and McLennan Magasanik associates:2008 〈http://www.coag.gov.au/reports/docs/HTSolar_thermal_roadmap.pdf〉.

[19] Yusaf T, Goh S, Borserio JA. Potential of renewable energy alternatives in Australia. Renewable and Sustainable Energy Reviews 2011;15:2214–21.

[20] Zahedi A. Australian renewable energy progress. Renewable and Sustainable Energy Reviews 2010;14:2208–13.

[21] Bhutto AW, Bazmi AA, Zahedi G. Greener energy: issues and challenges for Pakistan-solar energy prospective. Renewable and Sustainable Energy Reviews 2012;16(5):2762–80.